

# The evolution of disk galaxies in clusters \*

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## Abstract.

We are carrying out a programme to measure the evolution of the stellar and dynamical masses and  $M/L$  ratios for a sizeable sample of morphologically-classified disk galaxies in rich galaxy clusters at  $0.2 < z < 0.9$ . Using FORS2 at the VLT we are obtaining rotation curves for the cluster spirals so that their Tully–Fisher relation can be studied as a function of redshift and compared with that of field spirals. We already have rotation curves for  $\sim 10$  cluster spirals at  $z = 0.83$ , and 25 field spirals at lower redshifts and we plan to increase this sample by one order of magnitude. We present here the first results of our study, and discuss the implications of our data in the context of current ideas and models of galaxy formation and evolution.

**Keywords:** Galaxy formation, galaxy evolution, galaxy clusters

## 1. Introduction

Ground-based and HST observations indicate that the disk galaxy population in rich galaxy clusters has experienced remarkable evolution since  $z = 1$ . It has been argued that the increase with time of the S0 fraction and the simultaneous decrease in the spiral fraction suggest star-forming spirals fall into distant clusters at much higher rates than nearby, and that these spirals ultimately become S0s when star formation is extinguished by the cluster environment. Recent hydrodynamical simulations of the interaction of the gaseous components of disk galaxies with the intracluster medium support these ideas (Quilis, Moore & Bower 2000).

The strong evolution of the cluster spiral population contrasts with the mild evolution observed in the field spirals to  $z \sim 1$  (cf. Vogt 2000,

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\* Partially based on observations collected at the European Southern Observatory, Chile (ESO N° 66.A-0376)



and references therein). To quantify the evolution of the cluster spirals, we are measuring the stellar and dynamical masses and  $M/L$  ratios for a sizeable sample of morphologically-classified disk galaxies in rich galaxy clusters at  $0.2 < z < 0.9$ . We present here the first results.

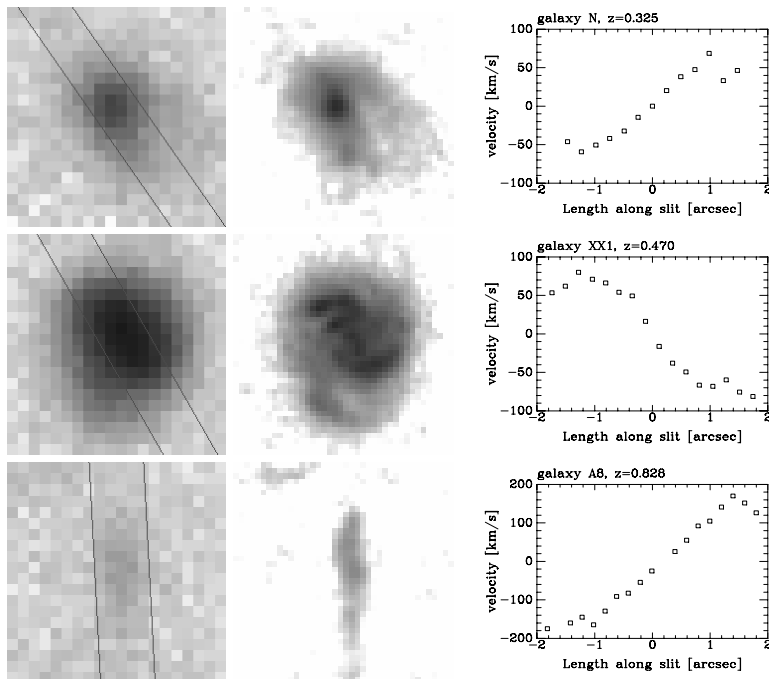
## 2. Rotation curves and the Tully–Fisher relation

The first cluster we have studied is MS1054–03 at  $z = 0.83$  (van Dokkum et al. 1999). Multi-object spectroscopy was obtained using FORS2 at the VLT. We selected 11 cluster members which were known to have [OII]3727 emission and 2 cluster members with disk morphologies but without known emission characteristics. For comparison purposes, the rest of the slits were placed on galaxies with spiral morphologies, and with magnitudes and colours similar to the known cluster disk galaxies. Since we wanted to measure rotation curves, the slits were aligned with the major axes of the galaxies. Two multi-slit masks were made at right angles to maximise the range of major-axis position angles that could be covered. The total exposure times were 3.5 hours per mask. We found evidence for rotation (tilted emission lines) in 9 of the known  $z = 0.83$  cluster galaxies, plus in 1 newly found cluster galaxy. In addition rotation was seen in about 25 foreground galaxies and 1 background galaxy. These field spirals provide a random field galaxy sample, observed with the same instrument and under the same observing conditions, and thus ideally suited for direct comparison.

Rotation curves were derived for the brighter emission lines in the sample from Gaussian fits at each spatial point along the slit (Figure 1). For all the emission lines,  $V_{\text{rot}} \sin i$  was also estimated visually from the 2-D spectra. The rotation curves in Figure 1 have not been corrected for the effect of seeing and slit-width. We are in the process of employing the synthetic rotation curve technique of Simard & Pritchett (1999) to extract  $V_{\text{rot}} \sin i$  from the 2-D spectra taking into account these effects.

Figure 2 shows a preliminary Tully–Fisher relation for a subsample of our galaxies. To ensure homogeneity, we only include morphologically-classified spiral galaxies (from HST imaging) for which the [OII]3727 line was observed (this excludes about 15 low  $z$  foreground galaxies). This subsample contains 7 foreground galaxies ( $z = 0.43\text{--}0.76$ ), 8 cluster galaxies ( $z = 0.83$ ), and one background galaxy ( $z = 0.90$ ).

Total magnitudes and ellipticities were measured in HST+WFPC2 F814W images (van Dokkum et al. 1999). The F814W magnitudes were transformed to the rest-frame  $B$ -band (Fukugita et al. 1995), and absolute magnitudes were calculated using  $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$  and  $q_0 = 0.05$ . No correction for internal extinction was applied.  $V_{\text{rot}} \sin i$

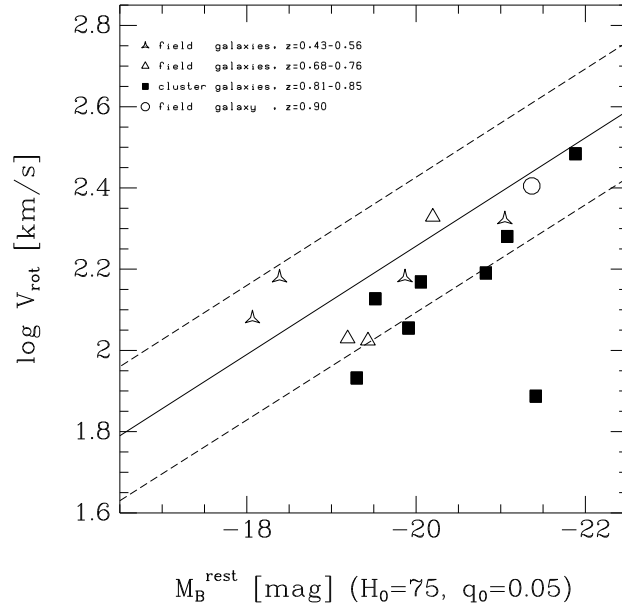


*Figure 1.* Three examples of the galaxies for which we have obtained rotation curves. From left to right the panels show: FORS2 R-band images ( $4'' \times 4''$  section,  $0.6''$  seeing) with the  $1''$  slits overlaid; the WFPC2 F606W images; and the preliminary VLT rotation curves with no correction for the line-of-sight inclination of the galaxy, nor for the effect of the slit-width and seeing. The first two galaxies are field galaxies, and the third one is one of our faintest cluster galaxies. Their magnitudes are  $R = 21.9, 20.8$  and  $24.0$  from top to bottom.

values were derived from the observed resolved [OII] emission lines, and  $\sin i$  was calculated from the ellipticities measured in the HST images.

### 3. Discussion

Figure 2 shows that at a fixed  $V_{\text{rot}}$  the high  $z$  cluster galaxies appear to be brighter on average than the high  $z$  field galaxies, and than the local relation. It is tempting to interpret this as the result of enhanced star formation on spiral galaxies falling onto the cluster. Our sample preferentially contains star forming spirals since we selected emission line galaxies from a rest frame  $B$ -magnitude limited sample. One could speculate that after this initial episode of enhanced star formation, the interaction with the intergalactic medium will remove much of the gas in these galaxies (cf. Quilis et al. 2000), and the star formation will cease. After an E+A phase the spirals could turn into S0s. However, we



*Figure 2.* Preliminary high redshift cluster and field Tully–Fisher relation. The solid line shows a local HI based TF relation for 32 cluster spirals from Pierce and Tully (1992), cf. Vogt (2000). The dashed lines show the 3 sigma limits. Filled symbols are cluster spirals, and open symbols field ones. The deviating cluster galaxy has uncertain morphological classification: edge-on disk with dust at the centre, or two almost overlapping edge-on disks.

must stress that a larger cluster sample, covering a range of redshifts, a more careful analysis of the data and detailed modelling are necessary to reach firm conclusions.

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### References

- Fukugita M., Shimasaku K., Ichikawa T., 1995, *PASP*, 107, 945
- Pierce M. J., Tully R. B., 1992, *ApJ*, 387, 47
- Quilis V., Moore B., Bower R., 2000, *Science*, 288, 1617
- Simard L., Pritchett C. J., 1999, *PASP*, 111, 453
- van Dokkum P. G., Franx M., Fabricant D., Kelson D., Illingworth G. D., 1999, *ApJ*, 520, L95
- Vogt N. P., 2000, in *ASP Conf. Ser. vol. 197*, p. 435